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Perceptual Process for Bicyclist Microcosmic Behavior

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Abstract

With their unique features, the bicycles exhibit chaotic and erratic trajectories in the kinetic process. It is suggested that this motion performs certain actions that can be represented as if they would be subject to perceptual process. Then demonstrate a new paradigm for the perceptual process could be interpreted as a chain psychological - physical process, which has illustrated a perceptual / behavioral / motorial approach to animating the bicyclist autonomously. Furthermore, the perception subsystem, which comprises a set of virtual online sensors, sensor data packet, and a perceptual focusers, obtains basic information about the ambient dynamic environment. The behavioral choice, situated between the sensory perception system and action system, is the most important part to respond to changes in the traffic environment. This system is used to weigh the pros and cons of the various acts and making decision through brain information processing. In addition, the action system is the basis for the rider to achieve a variety of behavioral function. Following part, this study extracts the bicycle/rider unit as fundamental element. During the kinetic process, individual visual perception plays particularly importance role. Hence, it is necessary to modeling the sight ranges dependent on velocity. Considering the movement of bicycle is anisotropic, tow smaller speed-dependent domains named reactive range and perceptive range, are proposed. The former indicates that individual may take actions to avoid potential collisions with obstacles invaded in its reactive range; while, the latter represents the obstacles could be felt within this range. Using this approach, it is possible to produce animations of bicycle/rider unit demonstrating a variety of behaviors.

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Keywords: bicycle behavior; psychological-physical process; chaining individual components; reactive range; perceptive range

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1. Introduction

In the past decades, researchers have brought a significant focus on traffic dynamic models with a physical approach. The reason for this change is that traffic dynamic characteristics studies provide fundamentals for traffic behavior exploration, and provide design for traffic facilities in order to accommodate theoretical and experimental data. Since 1990s, relevant studies have been conducted mainly in the areas of urban design and planning, as several models have been proposed and validated from computer simulations.

Generally, traffic modes typically include motor vehicles, non-motor vehicles, and pedestrian. Conventional traffic flow theories and traffic simulation models usually directed more attention on passenger cars. As early as the 1970s, a variety of approaches have been applied to describe the collective properties of motor vehicle traffic flow, including macroscopic models such as hydrodynamic models (Laval, 2006), gas-kinetic-based models (Helbing, 1998), and microscopic models such as the car-following models (Jiang, 2008), cellular automata models (Jia, 2011).

Meanwhile, several models of pedestrian traffic dynamics have been formulated during the last two decades. These models can be classified into macroscopic and microscopic ones. The macroscopic models frequently take density and traffic volume as mean value characteristics (Henderson, 1971; Li, 2001), while the microscopic models focus on individual pedestrian movement. Much attention has been attracted by microscopic approaches, which can be subdivided into rule-based and force-based models. The rule-based models including cellular automatic model (Kirchner, 2002) and lattice gas model (Jiang, 2007) evolve individual following and collision-avoiding predefined rules. The typical force-based models are the social force model (Helbing, 1995; 2000), magnetic force model (Okazaki, 1979), and centrifugal force model (Chraïbi, 2010).

Nevertheless, the existing literatures on technologies for non-motor vehicle are scarce. The reason may be that the non-motor vehicle mode, especially bicycle, is still not regarded as basic commuting means. Some publicized document about non-motorized vehicle and bicycle micro-simulation models are developed and mostly based on car following model (Hoque, 1994; Hossain, 1999; Jia, 2007; Li, 2009). To replicate the non-motor vehicle flow characteristics, a number of studies in China establish continuous models based on non-lane traffic theory. Examples of these models are the vector field model (Wang, 2003; Zou, 2007) and normative cyclist behavioral model (Huang, 2007). These microscopic models still treat the non-motorized vehicle as a smart car, describe the movement in two vertical directions, and consider the longitudinal and lateral headway separately. However, they do not consider non-motorized vehicles' distinct characteristic movements, such as filtering behavior, swerving and weaving pattern, tailgating and self-organization phenomena. For this reason, these models are not able to describe the interlocking style in high density.

On the foundation of theoretical and applied research, the bicyclist microcosmic behavior is regarded as study object. In this study, the spatially bicycle behavior are analyzed to describe microcosmic bicycle movement. The framework used to analysis the micro behavior is established. In the frame, the riding process is broken down into chain procedure from sensory perception to action. Accordingly, the reactive range and perceptive range models, which have composed of two sub models, is proposed for cyclist's perceptual, behavior choice and action.

2. Functional anatomy of bicyclist behavior

This paper refers to the hierarchical view introduced by Hoogendoorn (2002), and classifies bicyclist complex navigation into three levels: operational (basic riding behavior), tactical (server selection, path choice) and strategical (general traveling plan). It aims to get a model limited to the former two levels,

however, which can reproduce the main observables of bicycle dynamics in normal conditions.

2.1. Psychological-physical process

Based on Helbing's idea (1995; 2000), pedestrian behavioral changes are guided by so-called social forces. However, the bicyclist has his/her own thoughts, not merely obeys the social force law as a simple particle. As such, a sensory stimulation causes a behavioral reaction that depends on the personal aims and choices from a set of behavioral alternatives. The sensory stimulus, which drives an individual to ride on the desired speed and avoid obstacles, is the embodiment of psychological process. Primarily, the psychophysical process has to be considered when other bicyclists or barriers obstructed the target bicyclist.

Evidence is given by field survey that more than 80% of bicyclists were inclined to guarantee primary speed even to accelerate slightly to avoid other bicycle and obstacle in low-density conditions. Yet, that is entirely different from the assumption in social force model, which is suitable for competitive or panic behavior (Parisi, 2009). In addition, it could be a more comfortable lateral position for a bicyclist to align to the edge of the preceding objects. When the act of obstructing occurs, bicyclist has to avoid collision by choosing a direction that depends on the distribution of other bicycles and obstacles.

Physical process is used to describe the physical interaction between the target individual and other obstacles when they have physical contact, especially in high-density situations. Here, the works of Helbing (1995) and Lakoba (2005) are adopted to formulate the physical process.

As in the study of Helbing (1995), the psychological and physical force must represent the effect of the environment on the behavior to reproduce bicycle movement, while they describe the concrete motivation to act.

Several models are then proposed to reproduce the bicycle dynamic movement, namely, the bicycle/rider unit model, reactive and perceptive range model, psychological & physical force model, and the path choice model. A detailed account of the development of these four models will be provided in the following sections.

2.2. Framework of bicyclist behavior

The riding behavior is an integrated and complex behavior, which contains accessing information from external environment by the perceptual system, weighing the pros and cons of the various acts and making decision through brain information processing, and then acting the procedure.

Fig.1 is a schematic of a bicyclist situated in its virtual world, illustrating the perception, behavioral choice, and action subsystems. Those are chaining individual components.

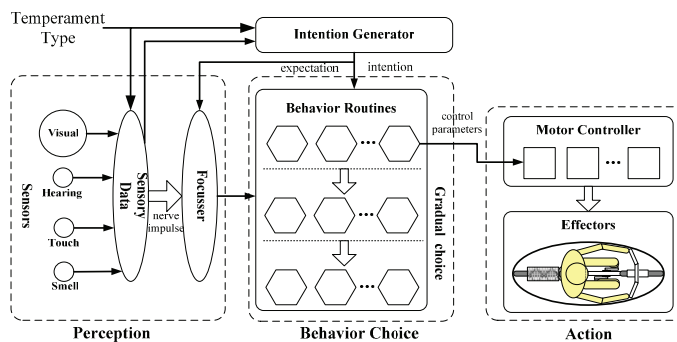


Fig. 1. Control and information flow in perceptual process

The perceptual process of bicyclist comprises two parts: body and brain, the former is a muscle-actuated biomechanical model, which contains the sensors and effectors, while the latter is a brain with perception, behavior choice, and motor centers.

(1) Sensory perception system

The perception system of bicyclist, illustrated in Fig.1, comprises a set of virtual online sensors, sensor data packet, and a perceptual focusers.

Perceptual system relies on a set of online receptors to obtain basic information about the ambient dynamic environment. Considering more than 80 percent information content from visual sense while in motion (Huang, 2010), the eyes are accepted as the most important perceptive organ. During motor process, the rider's eyes tend to produce a time-varying range named sight range, which area is relied to kinematic velocity.

Currently, the ideal perceptual system in brain is equipped with other two parts to process the sensory data — a sensory data memory and a focuser. The sensory data memory is a container, which is used to protect the data from the receptor. In addition, the focuser is a perceptual attention mechanism, which allows bicyclist to filter out the superfluous information for his needs of the immediate behavior routines. The brain focus mechanism provides the principle to make more attention to the current task. With the intention generator in the behavior choice system, the focuser could filter out redundant information for the current behavior needs to improve the efficiency of information processing. For example, the bicyclist attends to sensory information about avoiding other obstacles surrounding and ignores other expectation, when the defined risky obstacles invade in the target individual territory.

(2) Behavioral choice system

The behavior choice system of rider's brain, which is the most important part to respond to changes in the traffic environment, situates between the sensory perception system and action system (see Fig. 1). The intention generator, the rider's cognitive center used to simulate thinking organ, controls the rider's perception and harnesses the dynamics characteristics of the behavior cycle.

It takes a set of temperament type parameters and the sensory information from external events as input, and combines the rider's mental state in the internal needs to generate intentions. Here, the temperament type is used to describe the different riders' habit of behavior choices, faced in various traffic environments. The temperament type is innate characteristics determined by genetic factors and a relatively stable mental activity. Therefore, a group of parameters could be set to represent different temperament types of cyclists, to determine whether in groups, or tearaway, etc.

The temperament and perceived information are combined by the generate intention, which could produce a desired result or effect. A dynamic mental state comprises variables representing to speed up, avoid obstacles, and flock, whose values depend on sensory inputs. At each simulation time step, the generate intention could activate the corresponding behavioral procedure, and the motor selection entails combining the innate characteristics, the internal mental state, and the inputting of sensory information. By selecting the appropriate motion control parameters, the virtual rider would achieve the current intention progressively. The system behavior is considered in the selection layer, which is the microscopic behavior of the process.

(3) Action system

The action system is the basis for the rider to achieve a variety of behavioral function, which comprises the abstract model for the Bicycle/Rider Unit (BRU). Motion control is the system that the rider could control the movement of the bicycle to complete the cycling process through its effectors, such as hands, feet, limbs, etc. The processing is primarily accomplished through the action controller.

In each step of the simulation, the motor control mechanism ensures that the parameters could be established in order to update the rider position and velocity completely. The motor control activates

behavior routines that attend to sensory information and the choice from the behavior, and then to compute the appropriate motor control parameters to carry the bicyclist a step closer to fulfilling its immediate goals. At every simulation time step, the motor control could only to complete a task, such as forward, turn left etc. Further, these control parameters mechanism is translate into concrete action, as forward in accordance with the speed of 5.0m/s, and turning left at 15°.

3. Perceptual range for microcosmic behavior

In this section, we propose three ranges: sight range, reactive range, and perceptive range, which is solely based on psychological and physical process. In addition, these ranges respectively interrelated to the chaining individual components.

A two-dimensional road facility is considered here and is represented as a continuum with a domain, $\Omega \in \mathbb{R}^2$, source occurred boundary Γ_o , sink boundary Γ_s , and solid-wall boundary Γ_w ; that is, $\partial\Omega = \Gamma_o \cup \Gamma_s \cup \Gamma_w$. This model takes Newton's second law of dynamics as a guiding principle. Given an individual i with coordinates, it is possible to put the rules of bicycle behavior into the equation of motion.

To describe the bicycle movement accurately, several assumptions are made. First, all the bicyclists are skilled and able to control their bicycle to adopt an active driving style and to make progress using of opportunities. Besides, the surroundings with clean day, moderate climate, and dry smooth road are suitable for riding. In addition, the bicycles are assumed to be of the same size.

A bicycle cannot be considered as a point or a round object as usually modeled in the traditional pedestrian approach. Moreover, implementations of bicycle/rider unit model require them to be represented as an ellipse, which has compendious mathematical properties to match with realistic conditions (see Fig. 2).

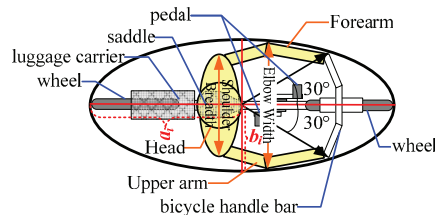


Fig. 2. Abstract of the Bicycle/Rider Unit

Ergonomic research shows that the movement of bicyclist should be most effective and comfortable while the hands operating with bilateral 30-degree direction each (Lai, 1997). The calculation indicates that along the bicycle moving direction the bicyclist's elbow defines the width, which is consistent with the observation. Then, if the bicyclist's pronasale is selected as the centre, the length of the bicycle will be the major axis ($2a_i$). Including the elbow joints, we can draw the unique minimum bounding circumscribed ellipse.

3.1. Sight range models

In the bicyclist's sensory system, visual perception plays particularly importance role during any dynamic process. In medical and traffic psychology study, a motor vehicle driver obtains more than 80% information by vision (Ren, 1993), and the proportion should be even higher in the bicyclist riding procedure. The uppermost access for bicyclist to perceive environment is vision, which has two practical aspects including field of vision (abbreviated FOV) and fixation point. FOV is the (angular, linear, or areal) extent of the observable world attained at any given moment. Furthermore, human's forward-facing

horizontal field of static view covers around 180 degrees typically, while the degree falls off with the increasing riding speed. Moreover, the fixation point changes continuously with speed. Hence, as the speed increase, the FOV becomes narrow and fixation point moves to the far field, which means bicyclist frequently focuses on the farther location while ignoring the nearby objects.

The relationship between speed and FOV can be obtained through data fitting (Eq. (1)) and the relationship between speed and fixation point (Huang, 2009) indicate the driver's fixation point ranges from 0.789s to 2.557s for the vehicle speed (Eq. (2)).

$$\vartheta_i(t) = 179.4 \exp(-0.05022v_i(t)) \quad (1)$$

$$l_i(t) = \mu_i \|\vec{v}_i(t)\| + a_i \quad (2)$$

where, $\|\vec{v}_i(t)\|$ is the magnitude of the vector speed (m/s) of individual i at time t ; $\vartheta_i(t)$ is the FOV; $l_i(t)$ is the fixation point; μ_i is a random variable to describe changes of fixation, and $\mu_i \in [0.789s, 2.557s]$; a_i is the major semi-axes of bicycle/rider unit model. Thus, the three variables ($\vartheta_i(t)$, $l_i(t)$, and μ_i) are temporal.

Further, the sight range model can be formulated by Eq. (3)

$$V_i(t) := \bigcap_{h \in H} V_h(t) \\ = \left\{ j : \|\vec{R}_j(t) - \vec{R}_i(t)\| \leq f_i(t) \right\} \cap \left\{ j : \arccos \frac{\vec{R}_j(t) \cdot \vec{R}_i(t)}{\|\vec{R}_j(t)\| \|\vec{R}_i(t)\|} \leq (\theta_i(t) - \vartheta_i(t)/2) \right\} \quad (3)$$

3.2. Reactive range models

A bicyclist has to be aware of the surrounding environment and make appropriate responses accordingly in time by experience. That is, he/she needs to scan whether there are dynamic and static obstacles such as other bicycles, pedestrians, vehicles, and others. The surrounding primarily consists of two ranges, named reactive range (Fig. 3) and perceptive range (Fig. 4). These ranges are the intrinsic attribution of each target individual for psychological influences. The former indicates that individual i may take actions to avoid potential collisions with obstacles invaded in its reactive range while the latter represents the obstacles, which could be felt within this range.

Because there is no rear view mirror, the bicyclist usually pays more attention to the front objects than those in behind, even under emergencies that require collision avoidance. In addition, it is observed that a bicycle is capable of preceding obstacles by an extremely small gap when it is aligning to the lateral edge of the obstacle. However, when the bicycle is aligned to the centre of the obstacle, a larger gap is required. Therefore, the movement of bicycle is considered as anisotropic.

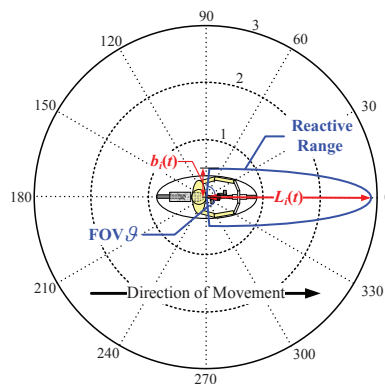


Fig. 3. Geometry of the Reactive Range for Bicycle

The blue gibbous curve is the reactive range of an individual, while the movement speed is 5m/s, the reaction coefficient is 0.3, reaction time is 1.24s, and safe reaction coefficient is 0.02. Furthermore, the parameters α_i and β_i are enthusiastic response to the intruder; their values determined by the size of reactive range. If there is any obstacle invading the reactive range, the bicyclist will change his/her speed and dodge away to avoid collision.

Because of the agile and smart size nature of bicycles, they have the advantage of using the clearance beside preceding obstacles efficiently. Then, this clearance becomes a reactive range for bicycles to escape from possible collision. That is, a rider maneuvers his/her bicycle to avoid collision when there are obstacles invading in its reactive range. Thus, the reactive range covers an elliptic sector that set bicyclist's pronasale as the center (see Fig 3).

Furthermore, the area of this range is influenced by riding speed, FOV, reaction coefficient, and reaction time of individual i . The boundary of reactive range $R_i(\theta, t)$ can be described by Eqs.s (4) to (6):

$$R_i(\varphi_i, \theta_{ij}, t) := R_i = \frac{L_i(t)b_i(t)}{\sqrt{L_i^2(t)\sin^2(\theta_{ij} - \varphi_i) + b_i^2(t)\cos^2(\theta_{ij} - \varphi_i)}} \quad (4)$$

$$L_i(t) := \alpha_i t_i \|\vec{v}_i(t)\| + l_f \quad (5)$$

$$b_i(t) := \beta_i \|\vec{v}_i(t)\| + b_i \quad (6)$$

where, φ_i is the angle of individual i movement, and θ_{ij} is the line joining the centers of target bicycle i and obstacles j , further, $\theta_{ij} \in [-\vartheta_i(t)/2, \vartheta_i(t)/2]$. $L_i(t)$ is semi-major axis of the gibbous curve determined by individual speed $v_i(t)$, reaction time t_i , safe distance l_f (here l_f is the semi-major axis of the bicycle/rider unit a_i), and reaction coefficient α_i . And the smaller reaction coefficient, the shorter bicyclists would like to maintain clearance (Eq. (5)). In addition, $b_i(t)$ is the semi-minor axis determined by speed $v_i(t)$, safe reaction coefficient β_i , and semi-minor axis of the bicycle/rider unit b_i (Eq. (6)).

The set of all obstacles that influence bicyclist i at a certain moment is defined as

$$N_i := \{j : \|\vec{R}_j(t) - \vec{R}_i(t)\| \leq R_i \wedge j \text{ influence } i\} \quad (7)$$

3.3. Perceptive range models

In fact, the bicyclist can feel much more capacious in the reactive range, so it is assumed that the rider can perceive other bicycles, pedestrians, motor vehicles, and some static roadblocks within a certain range. Moreover, a tentative suggestion is proposed that there is an elliptical region named perceptive range (see Fig 4), which is also influenced by movement speed and personal experience.

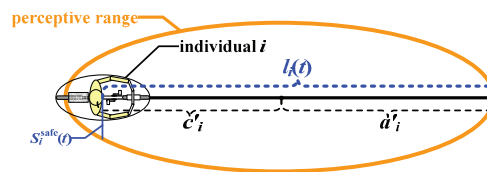


Fig. 3. Geometry of the perceptive range for bicycle

The orange elliptical region represents the perceptive range of an individual, while the movement speed is 5m/s, μ_i equals to 1.56, and personal sensory coefficient γ_i is 0.5. Therefore, the higher value of parameters μ_i and γ_i are, the wider the perceptive range is. Actually, the sum of semi-major axis a_i' and the distance from the center to either focus c_i' is the distance of fixation point $l_i(t)$; and when $\theta = \pi/2$, $P(\theta, t)$ is the semi-latus rectum $S_i^{safe}(t)$.

Given a bicyclist i with polar coordinates, the ellipse area with one focus in pronasale is defined as

$$P_i(\varphi_i, \theta_{ij}, t) := P_i = \frac{l_i(t) S_i^{\text{safe}}(t)}{l_i(t) - (l_i(t) - S_i^{\text{safe}}(t)) \cos(\theta_{ij} - \varphi_i)} \quad (8)$$

$$S_i^{\text{safe}}(t) := \gamma_i \|\vec{v}_i(t)\| + b_i \quad (9)$$

where $l_i(t)$ is the fixation point calculated by equation (2); and $l_i(t)$ denotes the sum of semi-major axis a'_i and the distance from the centre to either focus c'_i of the abstract ellipse. It is possible to determine one fundamental microscopic parameter, $S_i^{\text{safe}}(t)$, of the interaction on the basis of empirical results. In fact, $S_i^{\text{safe}}(t)$ is the semi-latus rectum of the perceptive range ellipse. Further, $S_i^{\text{safe}}(t)$ is the transverse safe distance related to speed $v_i(t)$, personal sensory coefficient γ_i , and semi-minor axis of the bicycle/rider unit b_i .

The set of all obstacles that bicyclist i can feel at a certain moment is expressed as

$$O_i := \{j : \|\vec{R}_j(t) - \vec{R}_i(t)\| \leq P_i \wedge j \text{ felt by } i\} \quad (10)$$

The two defined ranges focus on different issues. The reactive range covers the simple or standard stimuli, like slowing down and dodging those situations, is well predictable. The perceptive range specializes in modelling the complex situations, such as path choices with probabilistic models.

3.4. Relationship of the three ranges

In the previous sections, the reactive range was developed to simulate the basic one-on-one interactions between a bicycle and another object on the basis of the principle of collision and overlap avoidance. The reactive range model is useful for representing how a bicycle maintains a proper distance. However, it is imitated in terms of describing how a bicyclist actively attempts to choose an appropriate path through the traffic jam when he/she encounters a cluster of obstacles. The inevitable question is why a larger reactive range, which contains more objects around the target individual, using the resultant law to determine the movement direction, is not chosen.

There are two possible reasons. From the rider's viewpoint, there are indeed two ranges and the perceptive range is larger than the reactive one. This means the bicyclist may see the objects, yet not to react to them. Comprehensively, the computational complexity will increase with the expanded reactive range, and the simulation efficiency will diminish substantially. Therefore, a path choice model to describe bicyclists' decision-making process is proposed.

Based on practical observation, the path choice behaviour is viewed as a short-term plan to determine to which direction the bicyclist wants to move. Moreover, the decision-making process touches upon several factors, such as the instantaneous speed of individual i , speed of objects in front or at the oblique front, the lateral clearance between objects in front and i , the distance to the boundary, the number and size of objects near the target bicycle, and so on. These factors will all affect the path choice of the target bicycle. Furthermore, the first three factors have been realized by considering the psychological process, while the latter two can be summarized into the ambilateral density contrast for target bicycle move direction.

Since a bicyclist is used to the situations he/she normally confronts with, his/her reaction is usually rather automatic, and his/her behaviour is determined by his/her experience of which reaction is the most appropriate. It is, therefore, possible to put the rules of path choice into a motional model to predict bicyclist behaviour.

4. Conclusions

In this paper, a perceptual process is introduced for individual bicyclist behaviour to represent the main

observables of bicycle dynamics motion under normal conditions.

It focuses on discussing the essential differences between bicycles and passenger cars, pedestrian from several viewpoints, therefore the unique behaviour patterns of bicycles were characterised. As the cognition theory analyzes that the change process from cyclist received information to response, this study then further suggested that the cyclist's behaviour is a chaining individual components. Further analyse of cyclist's micro behaviour is carried out to construct the general framework including the system of perceptual, behaviour choice and action. This study extracts the bicycle/rider unit as fundamental element, which is represented as an elliptical individual. During any kinetic process, individual visual perception plays particularly importance role. Hence, it is necessary to modelling the visual field which to be dependent on velocity. Considering the movement of bicycle is anisotropic, tow smaller fields named reactive range and perceptive range, are proposed. The former is a speed-dependent domain, which indicates that individual may take actions to avoid potential collisions with obstacles invaded in its reactive range; while, the latter represents the obstacles could be felt within this range.

Further studies must be conducted the individual as self-determined objects, and to model the perceptual process. Therefore, a continuous model needs to be proposed to describe the bicycle dynamic phenomena.

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